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A Proposal to Measure Nuclear Calibration Cross Sections for Protons between 100 and 1000 GeV

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ABSTRACT

We propose to measure the cross sections for the production of ^{24}Na and other high-threshold radionuclides in copper by protons in the energy range between 100 and 1000 GeV. We wish to determine these cross sections to three per cent accuracy by comparison with the results from a toroid.

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Introduction

Use of ^{24}Na production in copper to determine the number of protons in an extracted proton beam from a high energy accelerator has several advantages over methods previously used:

1. The effective threshold of around 400 MeV makes the result less sensitive to beam quality than most other reactions, e.g., ^{24}Na production in aluminum.[1]
2. The determination is less sensitive to thickness corrections since gamma rays are counted rather than alpha particles. Formerly, alpha particles were counted from the production of ^{149}Tb in gold.[2]
3. The proximity of the gamma-ray energy (1.369 MeV) to that of ^{60}Co (1.332 MeV) makes accurate determination of detector efficiency possible.
4. Measurements to date indicate that the cross section is essentially independent of energy from 10 GeV to 400 GeV. These results are given in Table 1.

The development of the high resolution Ge(Li) gamma-ray detector made it easy to separate the ^{24}Na 1.369 MeV gamma ray from the multitude of others resulting from the spallation of copper. Such a separation required peak-stripping techniques using the NaI (Tℓ) detectors available earlier. That precluded the routine use of the technique for beam intensity measurements.

Accurate determination of the number of protons incident on a target is a requirement for almost every experiment at a high energy accelerator. See Appendix A.

Toroids can be used when the current is high enough (typically 10^{11} protons or more in one millisecond). Individual protons can be counted accurately up to about 10^{6} per second. Outside these ranges foil activation is a valuable alternative since it can be used for calibrating instruments such as secondary emission chambers and ion chambers which monitor the number of protons. These instruments cannot be calibrated absolutely by passing a current through them as a toroid can.

The secondary emission chamber has a temporal response problem. The work function of the foil surfaces is very sensitive to many outside influences. Although the chamber is evacuated, residual gases react with the surfaces especially at locations heated and/or damaged by interactions of protons in the beam. Thus, a carefully calibrated secondary emission chamber can change its response in an unpredictable manner.

The ion chamber suffers primarily from recombination problems. Too high an ion density can result in a lower response because the ions recombine in the gas rather than traveling to the collection plates. The ionization process also exhibits relativistic effects which must be taken into account. This relativistic rise with momentum can require corrections as large as ten per cent.

There have been a few cross section measurements made at energies above 30 GeV in copper by comparison with a toroid (see Table 1) or by counting the number of protons[7]; however, there have been no systematic studies which will eliminate able to obtain protons of about 8 GeV, the energy of protons injected from the Booster accelerator, for a low energy check. The result of the measurements using the aborted beam will be a curve (probably a straight line at energies above 100 GeV) from which one will be able to determine the cross section at any energy from 8 GeV to about 1000 GeV.

III. Cross Calibration

We also propose to use this opportunity to cross calibrate the proton beams from Fermilab, CERN, and BNL. Since the radionuclides produced in copper have sufficiently long half-lives, foils from these irradiations can be taken elsewhere for counting on other systems. We propose to do such counting of Fermilab foils at CERN and Brookhaven. Following the completion of ISABELLE at Brookhaven, results of foil activation measurements there with protons of about 400 GeV can be compared with Fermilab foil results. Systematic differences between different counting systems will thus be eliminated, leading to a better cross calibration between the high energy physics laboratories having proton beams with energies above 100 GeV and easier comparison of results from such laboratories.

IV. Requirements

This experiment is most logically done as a series of irradiations in conjunction with accelerator studies. The following apparatus is needed:

of secondaries would be less than one hour. This beam time would be used for irradiation of titanium and copper foil packets and for putting thick foils in the aborted beam to purposely produce secondaries in the toroids.

We plan to make approximately five irradiations at each energy in the study of the energy dependence. Since we expect the cross section to be relatively independent of energy, only about five different energies should span the energy range. We would concentrate on one energy, 400 GeV, for the intercomparison and most accurate determination of the cross section.

The study of the energy dependence would be done in two phases:

1. From 8 GeV to 400 GeV using the Main Ring beam, and
2. Comparison of 400 GeV and one higher energy (probably 800 GeV) using the Tevatron beam.

Since each irradiation will require about 4×10^{14} protons, the total beam time required will be about six hours, assuming a 60 second cycle for the Tevatron and an eight second cycle for the Main Ring at about 2×10^{13} protons per pulse. We anticipate that only about four foil packets will be irradiated on any given day; therefore, elimination of controlled access is an important consideration.

VII. REFERENCES

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4. J. B. Cumming *et al.*, Phys. Rev. C14, 1554 (1976).

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ADDENDUM TO PROPOSAL NO. 631

In view of the two-year period now anticipated before the new abort dump will receive protons, consideration should be given to doing all but the energy dependence in the Neutrino Area. Because the beam spot size will be small (initially about 0.5 mm by 1.2 mm) and single-turn extraction will be used in aborting the beam into the abort dump, there is the potential for evaporating the foil material. We propose to investigate this potential in the Neutrino Area by comparing millisecond extraction with single-turn extraction. Single-turn extraction is available, has been used in the past in the Neutrino Area, and the periods of single-turn extraction required for activating the foils are very short. Thus, we believe single-turn extraction could be accommodated without disrupting the program.

The burden of performing portions of the experiment at different locations has prompted us to seek additional aid. We wish to submit the name of A. Soukas of Brookhaven National Laboratory as a collaborator on this experiment. He will supply needed expertise in the areas of instrumentation and chamber design.

To give a better understanding of sources of error in the measurement, we submit the following:

Source	Percentage Uncertainty
Uncertainty in detector efficiency	1.4
Uncertainty in foil thickness	approx. 1
Effect of beam spot size (attached curve, Fig. 1)	less than 1 for typical spot sizes
Effect of cascade build-up	less than 1
Toroid absolute calibration	less than 1
Effect of halo on toroid measurement	large*
Effect of halo on foil measurement	proportional to amount of halo
Statistical uncertainty (typical Ge(Li) spectrum, Fig. 2)	less than 1
Systematic uncertainties not mentioned above	less than 3, can be reduced

*Secondaries going through the material of the toroid or the electronics can produce changes in signal much larger than those which result from the same number going through the center of the toroid.

FIGURE 1. EFFECT OF OFF-AXIS SOURCE ON EFFICIENCY

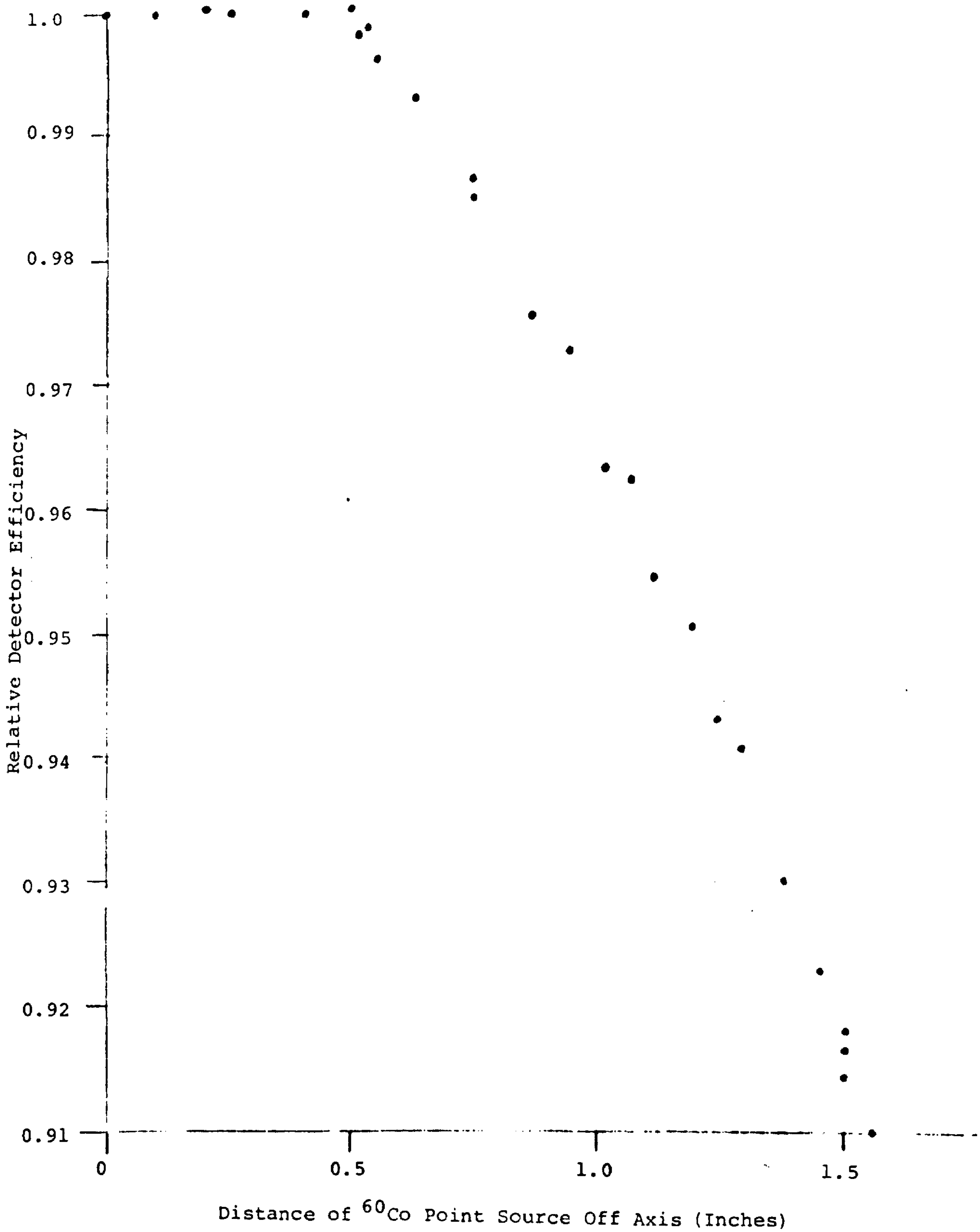

Figure 2. Ge(Li) Detector Gamma-Ray Spectrum for Copper Foil